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Supplementary appendix

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Supplementary Materials for

Association between mobility patterns and COVID-19 transmission in the USA: a mathematical modelling study

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Supplementary Text

Mobility Data

The real-time mobility data used in this analysis, initially provided as daily origin-destination (OD) matrices, was provided by Teralytics.¹ The data is based on aggregated and anonymized cellular data, covering 86 million people with a good coverage across all demographics and geos (with the exception of some midwestern states). From each phone they receive on average 150 cell tower pings evenly spread over each day. Teralytics processes the raw network event data and turn this into trip data by determining moving and stationary activity. The trip data is extrapolated up to represent the entire population by determining the home area of each phone and then compute an extrapolation factor for each phone based on the number of phones observed to have home locations in the area relative to the census population of the area. Through measuring mobile phones, this data includes every movement across all modes, including plane, car, public transit and walking. For the county level origin-destination matrix, an intra-county trip should have both origin and destination within the geographic boundary of the county, while an inter-county trips starts and ends in different counties. To be recognized as a trip, the non-moving time at each location should be at least 60 minutes, while for air travel, the stationary time is at least 240 minutes. Additionally, the trip distance must be higher than a defined lower bound which is a function of the density of cell towers and varies by area. This distance is typically around 500 meters for a dense urban city but can be up to several miles for a rural area. The 25 counties that are the focus of this analysis have good coverage. The data used in this analysis is provided as a supplementary file.

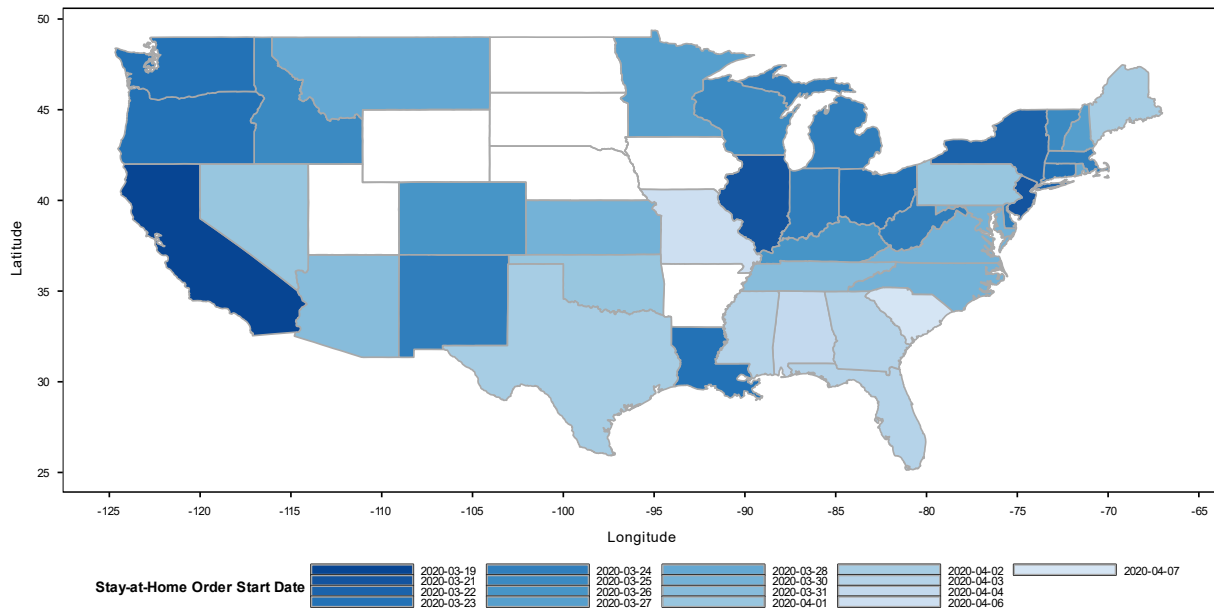


Figure S1

The start dates of stay-at-home orders for all U.S. states throughout March and April 2020.

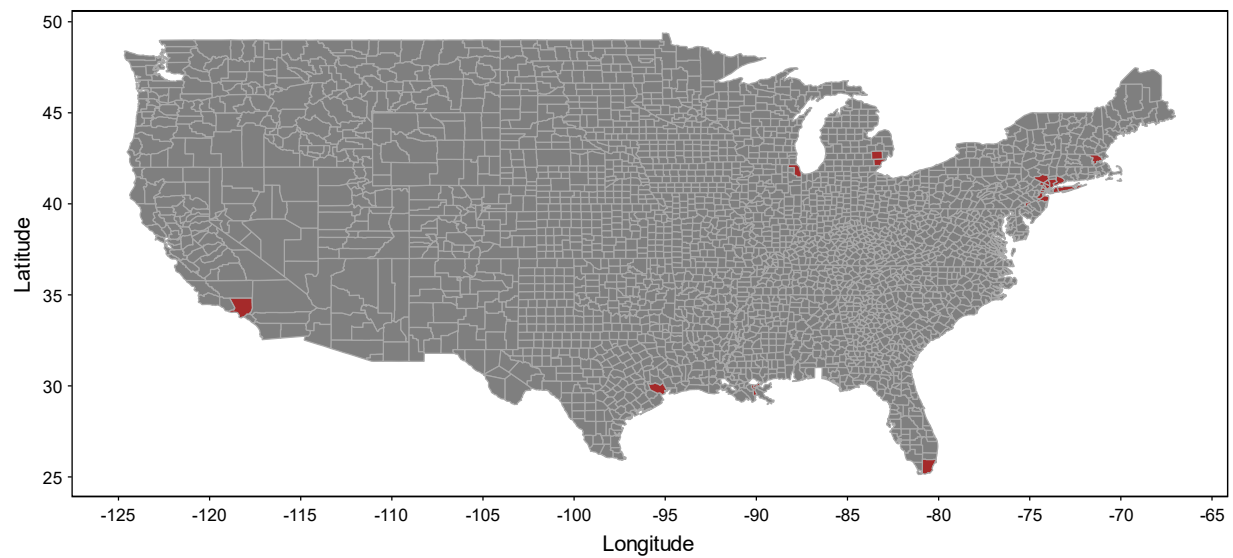


Figure S2

The location of the selected top 25 counties by total number of confirmed cases as of April 17.

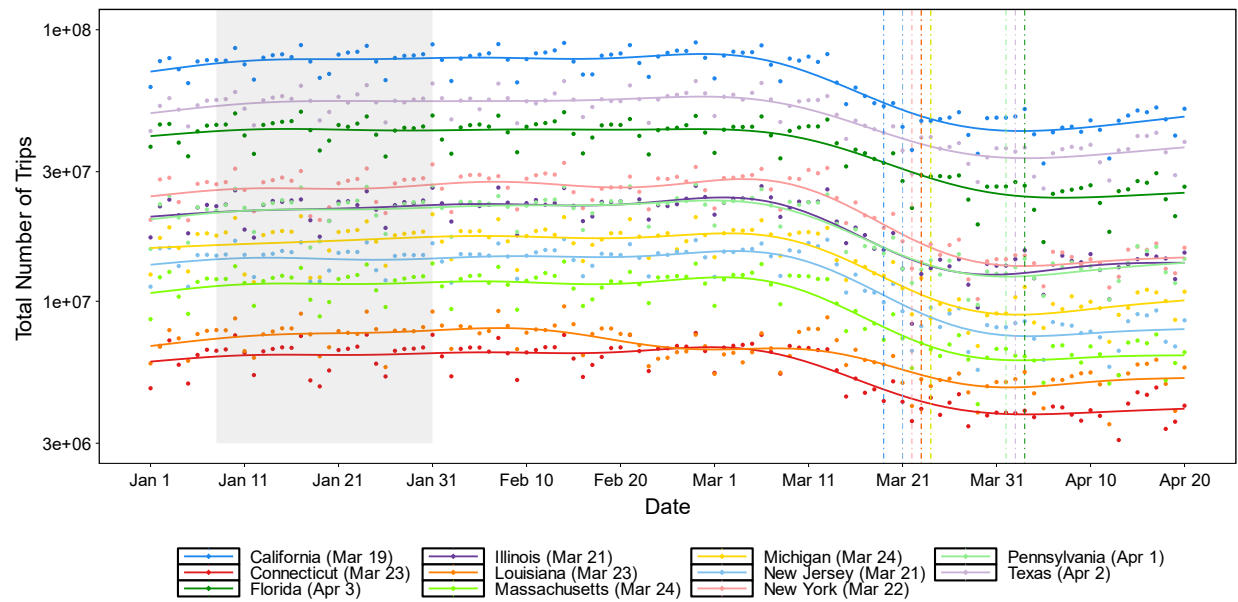


Figure S3

The total number of trips representing the sum of inflows, outflows, and internal trips for each state. The shaded window is the baseline period used to compute the mobility ratio (MR). The dates of stay-at-home orders are shown as vertical dashed lines for each state, and between parentheses in the legend (some dates overlap). The dots represent the raw mobility data while the plotted lines are smoothed using generalized additive model (GAM).

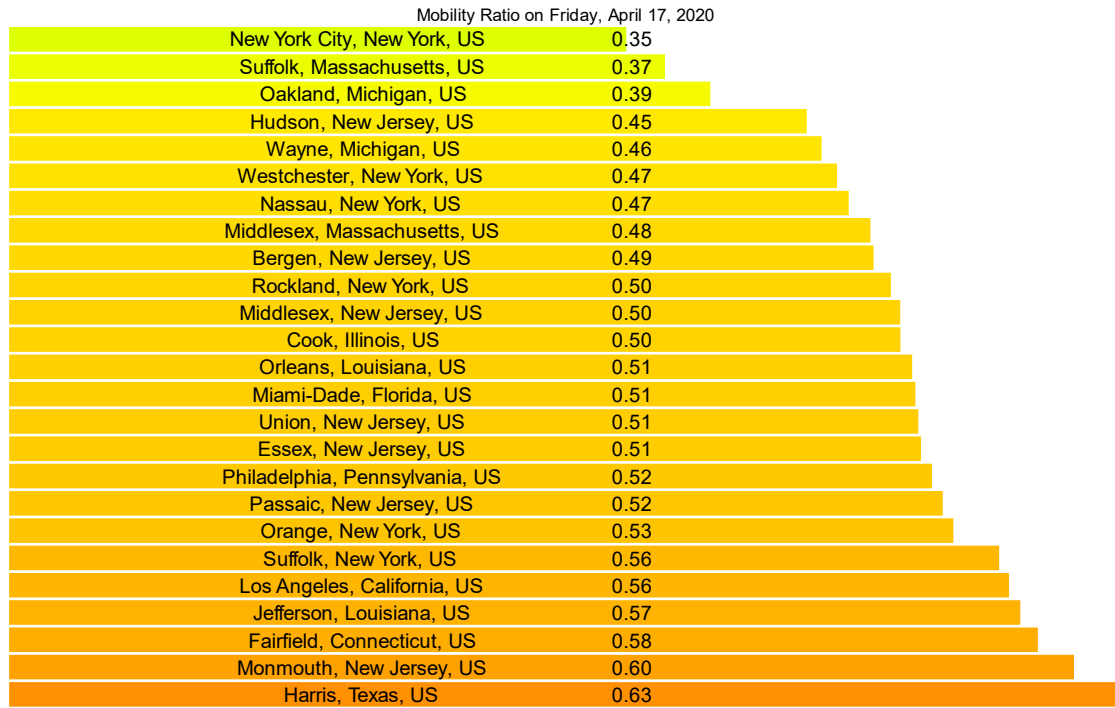


Figure S4

The mobility ratio (MR) for the selected top 25 counties by total number of confirmed cases on April 17, in ascending order.

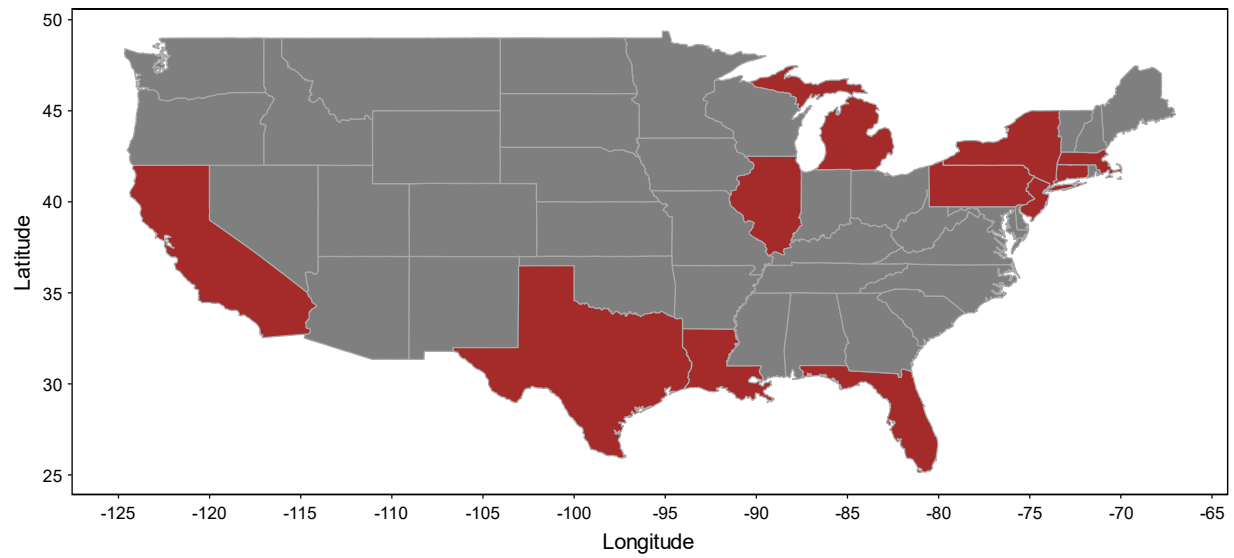


Figure S5

The location of the selected US states corresponding to the top 25 counties by total number of confirmed cases as of April 17.

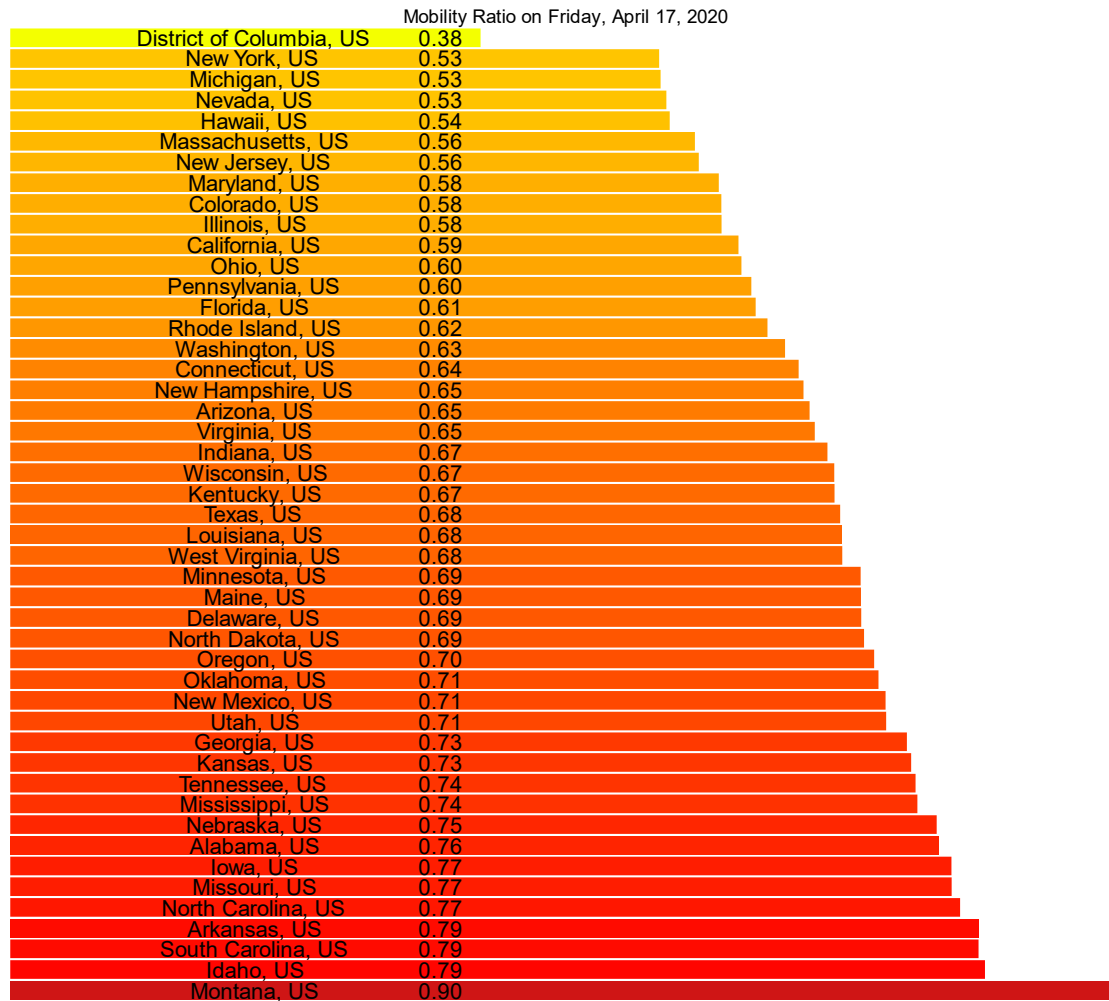


Figure S6

The mobility ratio (MR) for all US states on Friday, April 17, 2020; in ascending order.

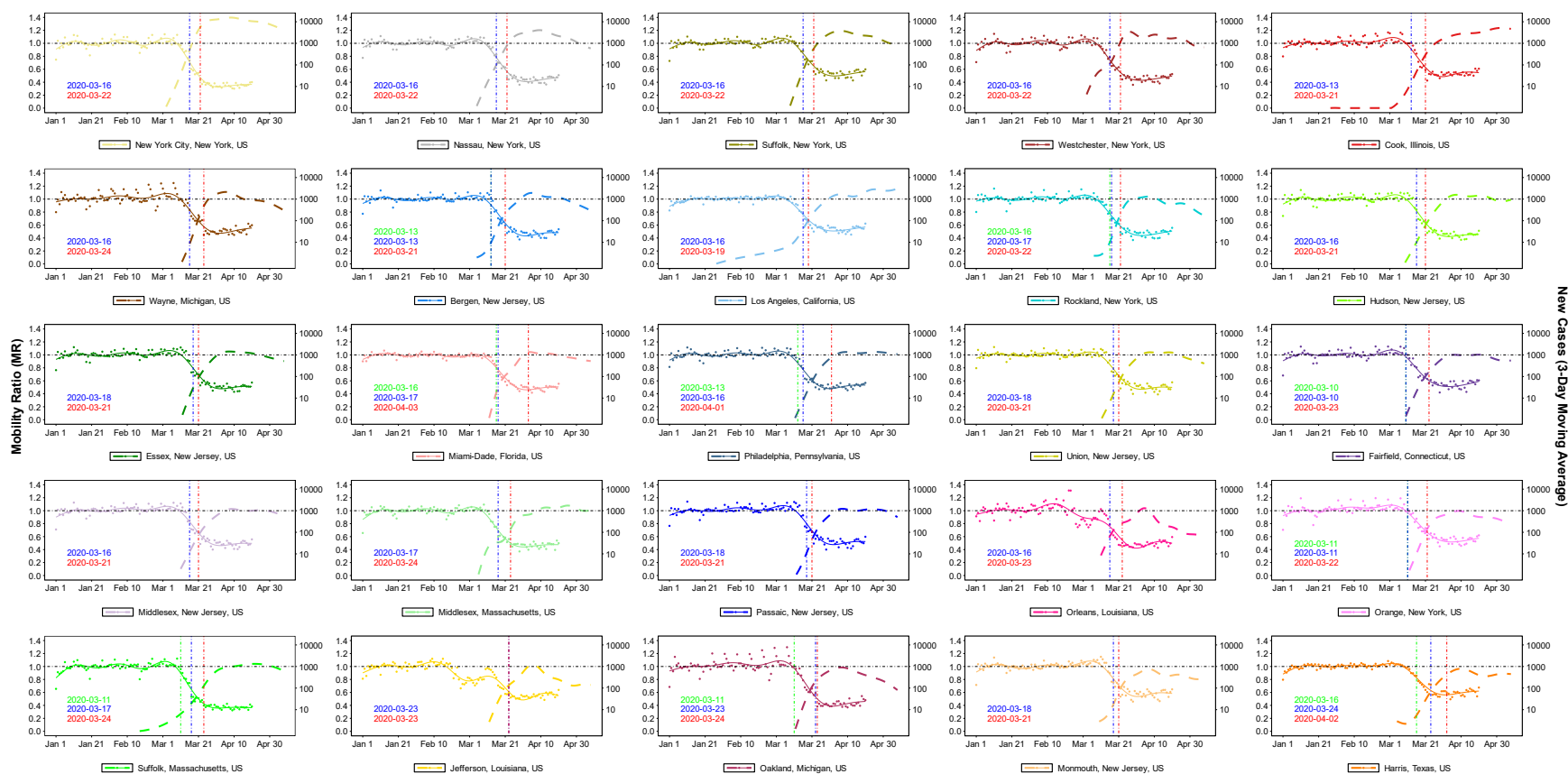


Figure S7

Timeseries of MR and three-day moving average of new daily cases (dashed lines) for the selected top 25 counties. The dates of state-level stay-at-home orders are shown as vertical dashed red lines, while the local school-closures and county-level social distancing orders are shown as dashed green and blue line, respectively. The dots represent the raw MR data points while the plotted lines represent the smoothed MR using generalized additive model (GAM).

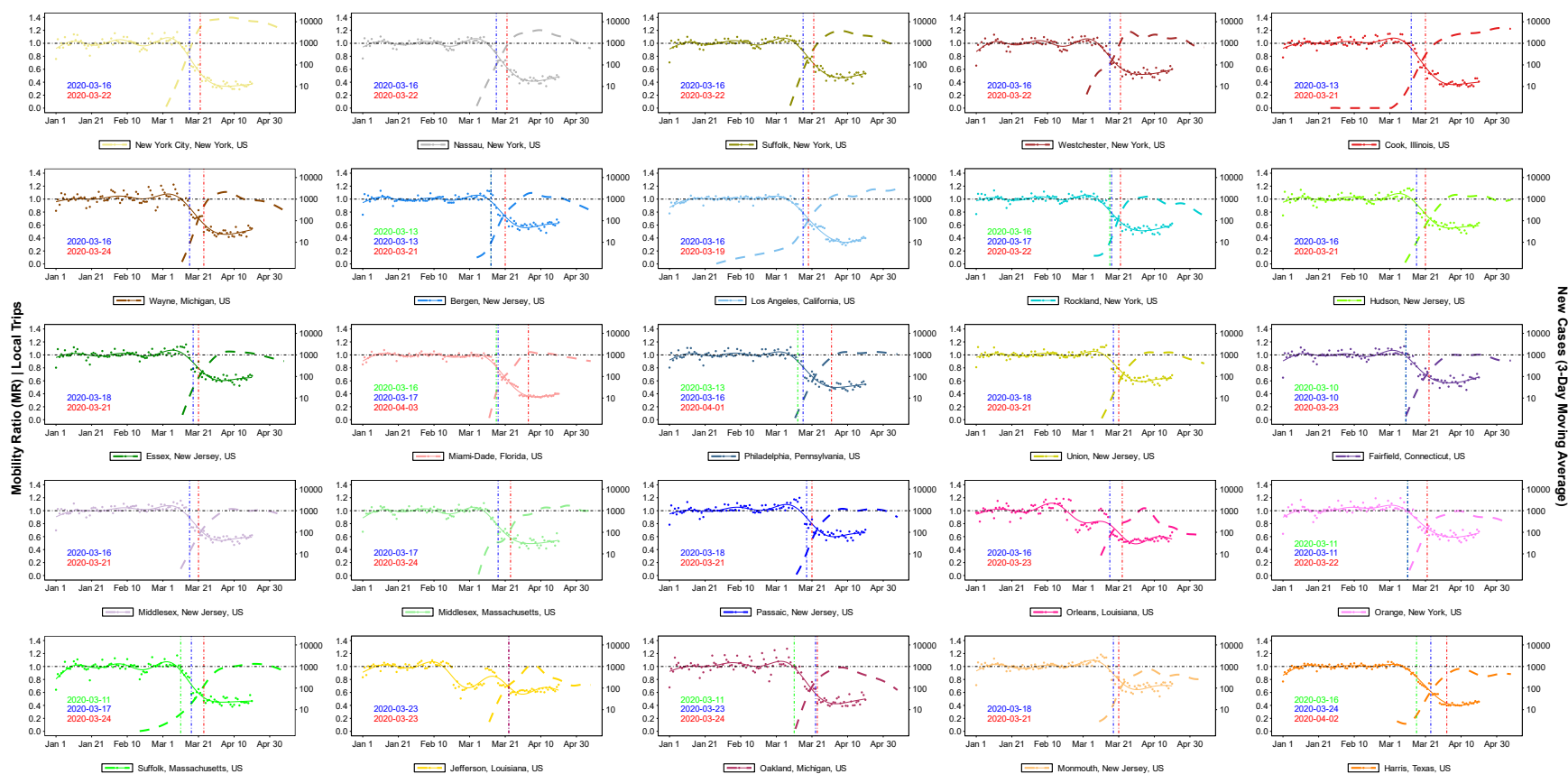


Figure S8

Timeseries of mobility ratio (MR) and three-day moving average of new daily cases (dashed line) based on internal trips (within county) only, for the selected top 25 counties. The dates of state-level stay-at-home orders are shown as vertical dashed red lines, while the school-closure and county-level social distancing orders are shown as dashed green and blue lines, respectively. The dots represent the raw MR data while the plotted solid lines are smoothed MR using generalized additive model (GAM).

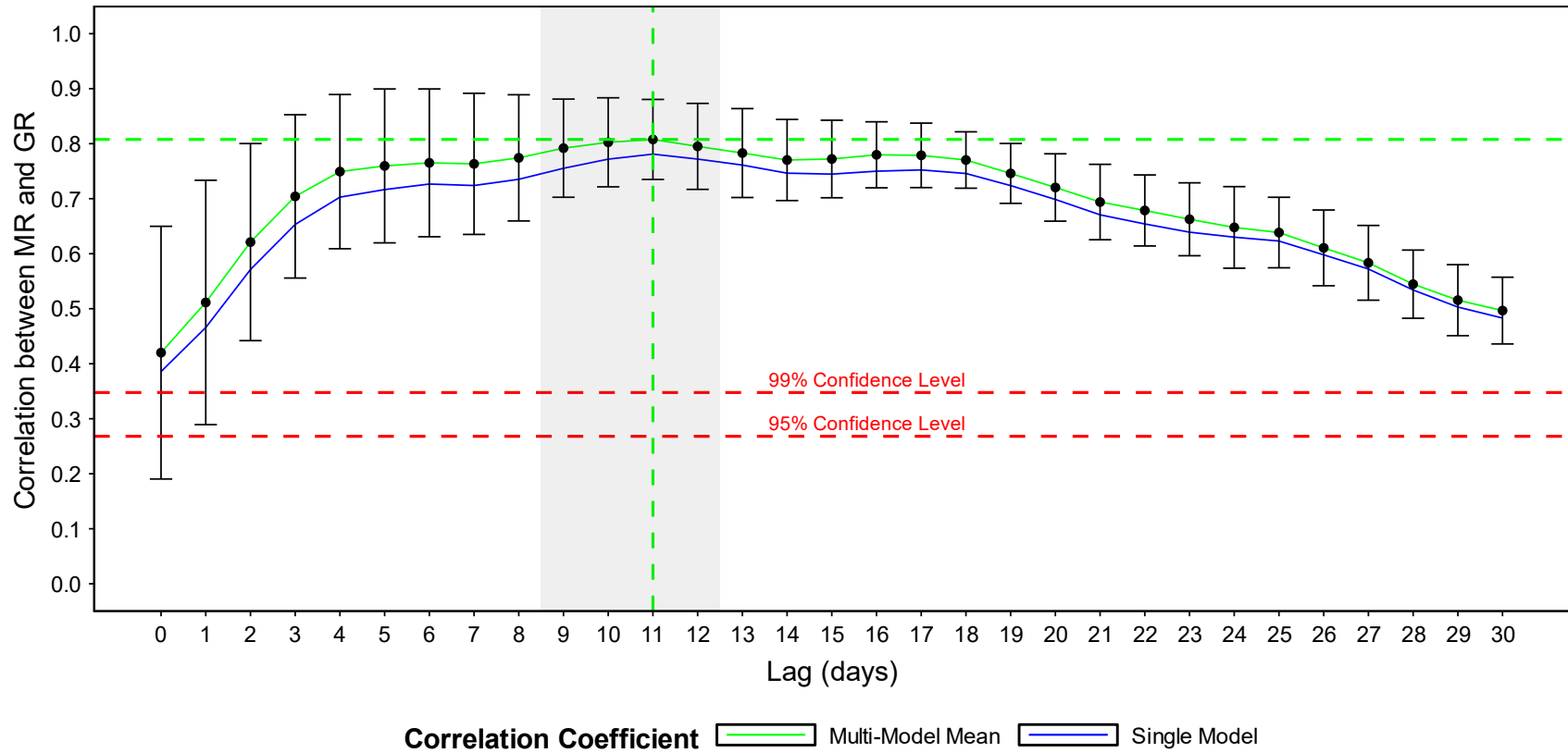


Figure S9

Mean and standard deviation of the correlations between mobility ratio (MR) and growth rate ratio (GR) at different lags (in days) for the single all-county model (blue line) and the mean (green line) and standard deviation (whiskers) of the county-specific model for the state-level analysis. All correlations are significant at 95% confidence level. The shaded window represents the optimal social distancing lag of nine to twelve days.

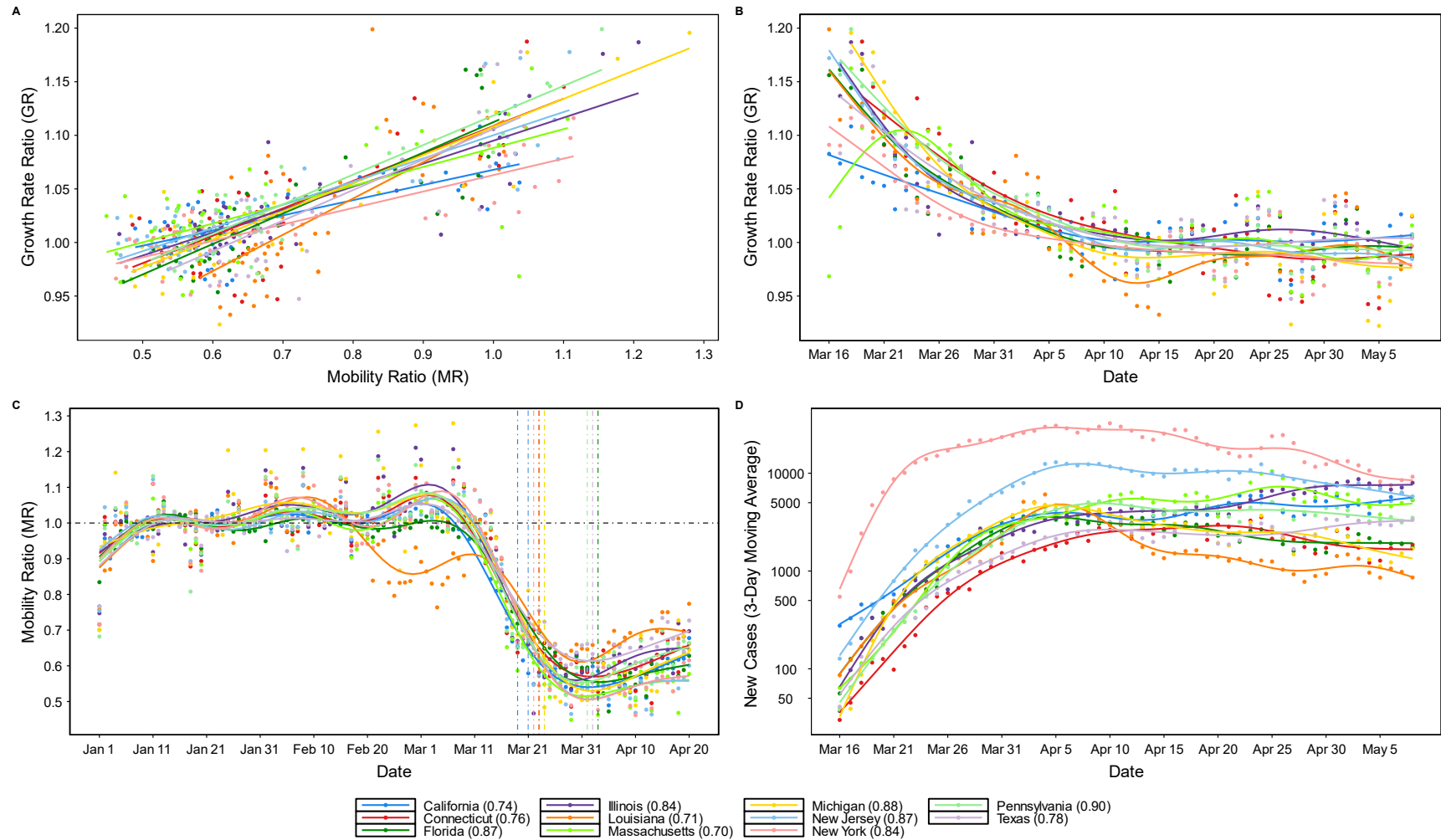


Figure S10

Relationship between mobility ratio (MR) and growth rate ratio (GR) given an eleven-day lag (A), with (B) growth rate ratio (GR) over time (C) mobility ratio (MR) over time and (D) daily confirmed cases over time for the eleven states of focus. Correlations are found to be significant at a 95% confidence level. The dates of stay-at-home orders are shown as vertical dashed lines for each state (some overlap) in (C). The dots represent the raw data while the plotted lines are smoothed using generalized additive model (GAM).

Table S1

Dates and times of stay-at-home orders for each US state, and the number of confirmed cases, deaths, and mobility ratio (MR) on April 17, 2020. The list is sorted by the stay-home order date. The eleven states highlighted are the focus of this study.

<i>FIPS</i>	<i>State</i>	<i>Stay-Home Date</i>	<i>Confirmed</i>	<i>Deaths</i>	<i>MR</i>	<i>Reference</i>
06	California	Mar 19	29157	1037	0.59	(2)
17	Illinois	Mar 21	27504	1131	0.58	(3)
34	New Jersey	Mar 21	77748	3837	0.56	(4)
36	New York	Mar 22	230597	17181	0.53	(5)
09	Connecticut	Mar 23	16314	1034	0.64	(6)
22	Louisiana	Mar 23	23062	1212	0.68	(7)
39	Ohio	Mar 23	9107	418	0.60	(8)
41	Oregon	Mar 23	1785	70	0.70	(9)
53	Washington	Mar 23	11183	603	0.63	(10)
10	Delaware	Mar 24	2295	61	0.69	(11)
18	Indiana	Mar 24	10154	522	0.67	(12)
25	Massachusetts	Mar 24	33642	1229	0.56	(13)
26	Michigan	Mar 24	29348	2206	0.53	(14)
35	New Mexico	Mar 24	1597	44	0.71	(15)
54	West Virginia	Mar 24	775	7	0.68	(16)
15	Hawaii	Mar 25	530	9	0.54	(17)
16	Idaho	Mar 25	1609	41	0.79	(18)
40	Oklahoma	Mar 25	2357	131	0.71	(19)
50	Vermont	Mar 25	769	35		(20)
55	Wisconsin	Mar 25	4053	206	0.67	(21)

08	Colorado	Mar 26	8595	371	0.58	(22)
21	Kentucky	Mar 26	2435	136	0.67	(23)
27	Minnesota	Mar 27	2070	111	0.69	(24)
33	New Hampshire	Mar 27	1285	3	0.65	(25)
02	Alaska	Mar 28	309	5		(26)
30	Montana	Mar 28	422	8	0.90	(27)
44	Rhode Island	Mar 28	3387	3	0.62	(28)
20	Kansas	Mar 30	1330	47	0.73	(29)
24	Maryland	Mar 30	11572	334	0.58	(30)
37	North Carolina	Mar 30	6045	177	0.77	(31)
51	Virginia	Mar 30	7491	164	0.65	(32)
04	Arizona	Mar 31	4511	141	0.65	(33)
47	Tennessee	Mar 31	5804	140	0.74	(34)
11	District of Columbia	Apr 1	2476	86	0.38	(35)
32	Nevada	Apr 1	3426	141	0.53	(36)
42	Pennsylvania	Apr 1	29888	921	0.60	(37)
23	Maine	Apr 2	826	29	0.69	(38)
48	Texas	Apr 2	17849	451	0.68	(39)
12	Florida	Apr 3	24755	725	0.61	(40)
13	Georgia	Apr 3	16159	643	0.73	(41)
28	Mississippi	Apr 3	3793	140	0.74	(42)
01	Alabama	Apr 4	4571	148	0.76	(43)
29	Missouri	Apr 6	4920	166	0.77	(44)
45	South Carolina	Apr 7	4099	116	0.79	(45)

Table S2

Dates of local directives for each the top 25 US counties, including the early actions taken, public school closures, and the corresponding state stay-at-home order dates. The list is sorted by the date of public-school closure.

<i>FIPS</i>	<i>County</i>	<i>State</i>	<i>Early Local Directives (Partial School Closure and/or Cancellation of Large Events)</i>	<i>Other Local Actions</i>	<i>Public School Closure (County or State Directives)</i>	<i>Actions Taken</i>	<i>State Stay-Home Date</i>	<i>Time Difference** (days)</i>	<i>Reference</i>
36071	Orange	New York	Mar 11	Mar 11	Mar 11	Orange County Public Health Commission encourages postponement or cancellation of large events for next 14 days	Mar 22	11	(46)
17031	Cook	Illinois			Mar 13	Select schools and Cook County Districts transition to remote learning	Mar 21	8	(47)
34003	Bergen	New Jersey	Mar 13		Mar 13	Close public schools - transition to remote learning	Mar 21	8	(48, 49)
06037	Los Angeles	California		Mar 16	Mar 16	County Public Health Officer order to Prohibit gatherings with more than 50 people through at least 1 April, encourages social distancing; LA County	Mar 19	3	(50, 51)

						Office of Education recommends all schools transition to remote learning through March 27			
09001	Fairfield	Connecticut	Mar 10	Mar 10	Mar 16	Encourages social distancing, and hand- washing, large group events postponed, field trips on hold	Mar 23	7	(52)
22071	Orleans	Louisiana			Mar 16	New Orleans Mayor issues proclamation guidance 3-20-20, restrictions on public gatherings, have restaurants to have take- out only	Mar 23	7	(53)
26163	Wayne - Detroit	Michigan			Mar 16	Closure of Detroit Public schools through April 5 via Governor Executive Order	Mar 24	8	(54)
34017	Hudson	New Jersey			Mar 16	Hoboken Public Schools close for two weeks	Mar 21	5	(55)
34023	Middlesex	New Jersey			Mar 16	Middlesex Public Schools close March 16- 20, 2020	Mar 21	5	(56)
36059	Nassau	New York			Mar 16	Public schools close for two weeks	Mar 22	6	(57)

36061	New York City***	New York			Mar 16	Public schools close for two weeks via Gov Exe. Order	Mar 22	6	(58)
36103	Suffolk	New York			Mar 16	Public schools close for two weeks via Gov Exe. Order	Mar 22	6	(59)
36119	Westchester	New York			Mar 16	Public schools close for two weeks via Gov Exe. Order	Mar 22	6	(60)
42101	Philadelphia	Pennsylvania	Mar 13		Mar 16	Postpones school sponsored trips, installation of hand sanitizers in schools, athletic facilities closed to outside organizations. Mar 16, School District of Philadelphia, closure of schools 16 Mar - 27 Mar	Apr 1	16	(61)
12086	Miami-Dade	Florida	Mar 16	Mar 16	Mar 17	County Exe. Order, Closures of congregate meal sites and community centers; Closure of movie theaters, food-service to take-out and delivery only	Apr 3	17	(62)
25017	Middlesex	Massachusetts			Mar 17	All Massach. Public schools closed March 17 - April 6 via Gov Exe. Order	Mar 24	7	(63)

25025	Suffolk	Massachusetts	Mar 11	Mar 17	Mar 17	Boston Pub Health Officials Close Eliot K-8 Schools; effective date District wide closure of Boston Public Schools	Mar 24	7	(64)
36087	Rockland	New York	Mar 16	Mar 16	Mar 17	County state of emergency with actions; Rockland County Public Schools close for at least two weeks	Mar 22	5	(65, 66)
34013	Essex	New Jersey			Mar 18	All NJ public schools closed via Gov. Exe. Order	Mar 21	3	(67)
34025	Monmouth	New Jersey			Mar 18	All NJ public schools closed via Gov. Exe. Order	Mar 21	3	(67)
34031	Passaic	New Jersey			Mar 18	Passaic County Public Schools close in-person learning via Gov Exe Order	Mar 21	3	(68)
34039	Union	New Jersey			Mar 18	All NJ public schools closed via Gov. Exe. Order	Mar 21	3	(67)
22051	Jefferson	Louisiana			Mar 23	Gov Order	Mar 23	0	(69)
26125	Oakland	Michigan	Mar 11	Mar 11	Mar 23	Detroit cancels St. Patricks Day parade; Closure of Detroit City Public Schools (Gov. order) through 6 April	Mar 24	1	(70-72)

48201	Harris	Texas	Mar 16	Mar 24	County Exe. Order Closure of Houston and Harris County schools, indoor dining closure of bars and restaurants; County stay home, stay safe order	Apr 2	9	(73)
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** County or State Directives*

*** Time difference in days between local public school closure and state stay-at-home order.*

**** In order to be consistent with the CSSE COVID-19 dashboard reporting (5), New York City is used to represent New York County, Queens County, Bronx County, Kings County, and Richmond County in one location.*

Note: C = County directive. S = State directive. GEO = Governor's Executive Order.

Video S1

An animation (*Mobility_Ratio.mp4*) of the 7-day moving average of the mobility ratio (MR) timeseries until April 20, 2020 for all US counties nationwide. The greyed-out area in the Midwest are filtered due to low coverage in the Teralytics data set (*1*). This includes all counties with a total trip counts less than two standard deviations below the mean.

Data S1

CSV file (*COVID19_MR_County.csv*) for the data used in this study at the county level, including timeseries of COVID-19 confirmed cases, deaths, and mobility ratio since February 1, 2020. The growth rate is derived from the confirmed cases.

Data S2

CSV file (*COVID19_MR_State.csv*) for the data used in this study at the state level, including timeseries of COVID-19 confirmed cases, deaths, and mobility ratio since February 1, 2020. The growth rate is derived from the confirmed cases.

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